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HIGGS DISCOVERY BEFORE LHC ?

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1 Introduction

The standard model (SM) of fundamental interactions, has been the successful theory over the last 25 years. The overall success of the SM in describing the elementary interactions, the discovery of gauge bosons at CERN in the eighties as well as the top discovery at Fermilab in 1995, strengthened the expectation that the Higgs mechanism is the one that gives mass to all particles. At the moment the Higgs particle is the only missing pieces of the puzzle.

The sensitivity of parameters of the electroweak theory to the mass of the top quark and of the W boson has been exploited to provide limits on the mass of the Higgs particle (M_H). Due to the logarithmic dependence of M_H to the ratio of M_W/M_{top}, a small change in the central values translates into a large change in the limit on M_H. At present (Spring 2001), the current 95% CL lower bound is 212 GeV/c^2 while the upper limit from LEP experiments is 113.5 GeV/c^2 with the additional hint of a possible signal at 115 GeV/c^2[1]. Due to its coupling Higgs decays into the heaviest possible pair of particles, therefore for M_H below 130 GeV/c^2 (low mass region) the most important channels are b or τ pairs, while for heavier masses, the branching fraction into vector boson pairs becomes dominant. A hadron collider provides excellent chances to discover the Higgs given that (in the low mass region) tagging of b-jets would be available. The tool became a reality at the Tevatron during the search for top and is now taken for granted in any experiment at hadron colliders.

In fig. 1 Higgs production cross section at 2 TeV is shown. While the gluon fusion mechanism is by large the dominating generating process, the signal over background ratio is such that at low mass the associated production of Higgs particle and vector boson (W,Z) is better suited for a discovery. At the Tevatron the interaction cross section is about 70 mb. About 70% of it provides events that are visible in the experiments

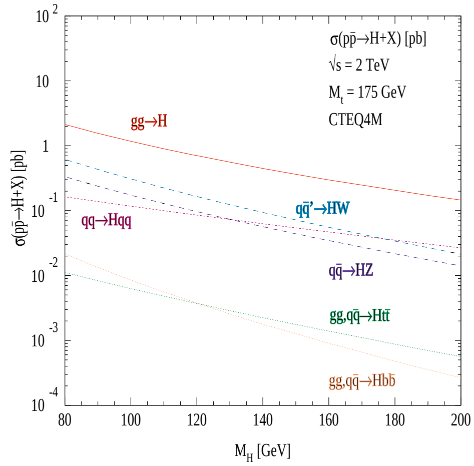

Figure 1: Higgs Production Cross Section

while the Higgs cross section is in the order of 1 pb or less. Therefore an efficient trigger must operate to provide a sample where to look for the needle in the haystack (1 in 10^{10} events).

In Run I CDF and D0 searched for Higgs produced in association with W and Z by exploiting samples of events collected with non-dedicated triggers. In specific both experiments looked in the "high P_T lepton" and in the "missing E_T" samples with the additional selection of two b-tagged jets. Despite the limited sensitivity to SM Higgs, the D0 and CDF analyses were useful to develop tools, study detector efficiencies and background. Those analyses also set the stage for studies dedicated to better understanding of the physics reach of CDF and D0 in Run II and demonstrated the key role assumed by b-tagging techniques in this search.

2 Run II Studies

The success of Run I paved the way to the upgrade of the Tevatron complex. This in turn lead to the upgrades of the CDF and D0 detectors. While the design energy (2 TeV in the center of mass) was not reached in Run I, the design instantaneous luminosity ($10^{30} cm^{-2} s^{-1}$) was routinely exceeded during the 1992-1995 data taking period. The experience gained during the high luminosity running led to an upgrade of the machine in which more luminosity was obtained by introducing more bunches (36x36 in Run IIa up from 6x6 in Run I). In this way the luminosity is increased while the average number of interactions per crossing is kept low. The price paid was the complete rebuilding of the front-end electronics to match the new interbunch (from 3.5 μs down to 396 ns in Run IIa and then 132 ns in Run IIb). At the same time CDF and D0 rebuilt their tracking systems. D0 added a magnetic field (2 T) and replaced the older tracking with a Fiber Tracker supplemented by a large silicon vertex detector (fig. 2). CDF replaced the old gas-based tracking chamber with a new drift chamber (the COT) and completely rebuilt the silicon system, which is now made of 7 layers of double sided silicon detectors, covering up to $|\eta| < 2$. It provides a standalone system with secondary vertex recognition capability. Furthermore CDF and D0 largely improved their triggering capabilities and are now able to identify high momentum tracks at

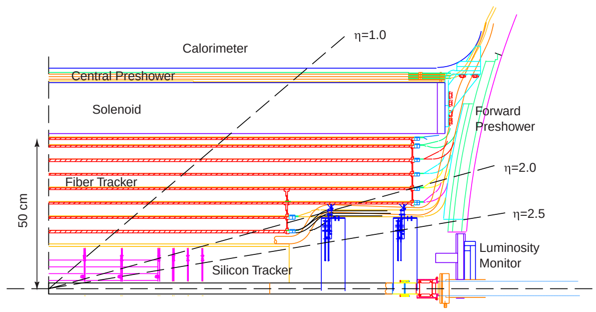

Figure 2: Cross sectional view of the D0 Upgrade

Level 1 (i.e. between crossings) and identify tracks displaced by the primary vertex at Level 2. The Secondary Vertex Tracker (SVT) is operational at CDF and the D0 Level 2 displaced vertex trigger (STT) will be operational next year [2, 3]. Both experiments also extended their capability to trigger on electrons and muons. The overall goal is to retain and exceed Run I physics capabilities through Run II.

CDF and D0 set forth a combined effort to understand the physics reach for Higgs searches of the two detectors[5]. In order to do so two complementary paths were followed: in one simple rescaling of results obtained in Run I was used, while at the same time a parametric Monte Carlo (based on performances averaged between CDF and D0) was tuned to reproduce Run I results. In this way we were able to estimate physics capabilities using backgrounds and efficiencies tuned on data. Essentially all mass spectrum was studied, although most of the efforts concentrated on the "low mass" region. In this region the most promising channel is the associated production of Higgs and vector boson (W or Z), with Higgs decaying into $b\bar{b}$ pairs. In the high mass region, where the Higgs decays into vector boson pairs, the events have a clean signature and the Higgs generation through gluon fusion becomes the most important production process. The results shown here are obtained by using the parametric Monte Carlo. This allows keeping into account the larger acceptances of the tracking system (and therefore the improved b-tagging capabilities) as well as improvements in the algorithms and in trigger capabilities. As the Higgs particle should also appear as a bump in the invariant mass of two b-jets, a lot of effort was devoted to an improvement of the jet energy resolution. In Run I, by using dedicated corrections, CDF was able to reduce the invariant mass resolution in its $Z \to b\bar{b}$ sample to 12%. Different studies shown that a 10% resolution is achievable. CDF plans to exploit the SVT to select a sample of $Z \to b\bar{b}$ events. D0 has similar plans based on its STT. This trigger will of course also select events containing Higgs [4]. The channels we present here are the low mass WH and ZH, with $H \to b\bar{b}$. We studied both the leptonic and hadronic decays of the W, the latter being affected by large backgrounds. In table 1 we show the number of events (signal and background) expected in 15 fb^{-1} for the WH (leptonic case). The sample is triggered on a high P_T lepton and is selected on additional requirements on missing E_T (>20 GeV) and two b-tagged jets. To enhance sensitivity to identify b jets from H decay, Run I studies shown that optimal results are obtained by a combination of a "strict" b-tagging algorithm (SECVTX) and of a "loose" algorithm. In this way the mis-tagging per jet is kept at ≈ 1 % leaving a situation dominated by physics background. To reduce background from $t\bar{t}$, all events with a second lepton are rejected, as well as events with additional jets. The final backgrounds are $Wb\bar{b}$, $t\bar{t}$, WZ and single top. All

$\mathbf{M_H}$	110	120	130
Signal events	75	60	45
$Wb\bar{b}$	435	375	285
WZ	90	60	30
$t\bar{t}$	225	300	330
single top	105	135	135
$\mathbf{S/\sqrt{B}}$	2.6	2.0	1.6

$\mathbf{M_H}$	110	120	130
Signal events	69	48	31.5
$Zb\bar{b}$	84	69	52.5
$Wb\bar{b}$	100	81	63
ZZ	43.5	3	0.0
$t\bar{t}$	70.5	64.5	52.5
single top	79.5	70.5	57
$\mathbf{S/\sqrt{B}}$	2.4	2.0	1.5

Table 1: Signal and background in 15fb^{-1} in the low mass region, WH channel (left), ZH channel (right)

of them, but for the single top, were measured in Run I and will be done again with better statistics in Run IIa.

Similar backgrounds plague the ZH channel. The most promising decay of the Z is the $Z \to \nu\nu$ channel where the events are collected by a missing E_T(> 35 GeV)trigger. The selection requires two b-tagged (loose and tight) jets, distance between the missing E_T vector and the closest jet to be >0.5 in $\eta - \varphi$ space, and the sum of hadronic energy to be below 175 GeV (to reduce $t\bar{t}$ background)(table 1). Less encouraging results are obtained in the full hadronic channel, where the W associated to the Higgs decays in two jets. $S/\sqrt{(B)}$ ratio is about or below 0.2 in 15 fb^{-1} for low mass Higgs. In the "high mass" region , where the WW* decay channel opens, the $gg \to H$ mechanism becomes the most important source due to the low level of background. While the main focus is on the final state $ll\nu\nu$, the trilepton channel where W(Z)H,$H \to W(Z)W^*W^*$, provides a sizeable contribution. In 15 fb^{-1} we expect S/$\sqrt{B}$ in excess of 2 for M_H >150 GeV/c^2. Table 2 shows the results relative to this region. The (combined) CDF and

$\mathbf{M_H}$	140	150	160	170	180
Signal events	39	42	22.5	16.5	15
Total background	660	450	66	36	57
$\mathbf{S/\sqrt{B}}$	1.5	2.0	2.8	2.75	2.0

Table 2: Signal and background in 15fb^{-1}in the high mass region

D0 expectations are shown in fig.3 where M_H vs. luminosity is shown [5]for the whole mass range $80 < M_H < 180 GeV/c^2$. The three bands correspond to 95 % CL, 3σ and 5 σ effect. The lower limit of the band corresponds to the results obtained by this study, while the width has been obtained by considering a (positive only) 30% uncertainty.

3 Run IIb

While 15 fb^{-1} appear to be the amount of data needed, only 2 fb^{-1} are foreseen for Run IIa. The Fermilab Directorate launched a program to upgrade the Tevatron accelerator complex in order to deliver 15 fb^{-1} by 2007. In order to work the upgrade requires the use of electron cooling to efficiently recycle the antiprotons, as well as to keep the beam-beam tune shift under control using the TEL (Tevatron Electron Lensing)

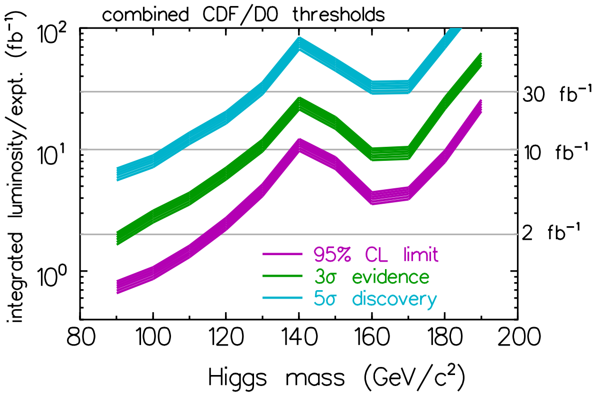

Figure 3: Final results for Higgs searches, CDF and D0 combined

which will allow a relatively modest crossing angle. Therefore, although upgrade of the Tevatron seems feasible, there are some challenges to be met in order to bring the instantaneous luminosity of the machine from 1÷2x$10^{32} cm^{-2}s^{-1}$ to 5x10^{32}, i.e. to about 5 interactions/crossing. At the same time there will be a challenge for the detectors to match this new environment. The replacement of (at least) the innermost layers of silicon detectors is already foreseen as they were designed for a Run II of 2 fb^{-1} while the detectors must survive to 7 times as much luminosity. An aggressive R&D and design phase has started to define the other modifications which are needed to match this new challenge.

4 Conclusion and Acknowledgments

The CDF and D0 experiments were able to set the tools for Higgs searches at the Tevatron Collider already in Run I. While the luminosity foreseen for Run IIa is probably not enough to discover the Higgs, the Run IIb, which will allow each detector to collect 15fb$^-$1. This, together with the improvements of the tracking and calorimeters of each detector, will open the possibility to discover the Higgs both in the low mass (below 130 GeV/c^2) and above 150 GeV/c^2. I would like to thanks E.Barberis, W.Yao, G.Velev from CDF and D0 for the discussions and comments and P.Derwent of the Fermilab Beams Divisions for the information on the Run IIb upgrade projects of the accelerator.

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